

Deep Space 1 Flight Experience: Adventures on an Ion Drive

Steve Collins

Jet Propulsion Laboratory
California Institute of Technology

25th ANNUAL AAS GUIDANCE AND CONTROL CONFERENCE

February 6-10, 2002
Breckenridge, Colorado

Sponsored by
Rocky Mountain Section

New Millennium Program Deep Space 1

Successful Validation of 12 Breakthrough Technologies

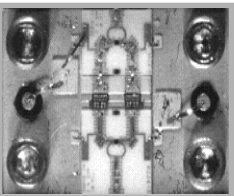
- Ion Propulsion System: enables rapid access to deep space
- AutoNav: first totally autonomous on-board navigation system; first deep-space low-thrust Nav
- Total mission cost including launch vehicle and operations = \$160 M
- 39 months from pre-phase-A to launch, 38 months flight operations



Small Deep Space Transponder

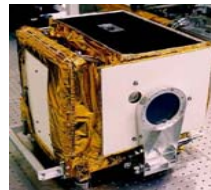
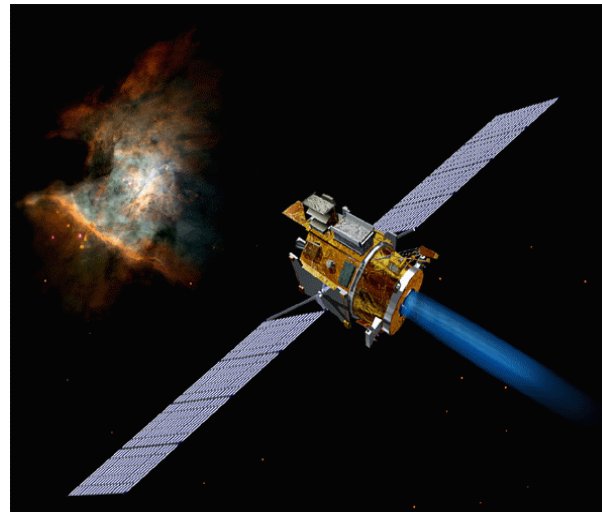


Low Power Electronics

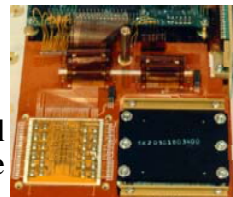


Ka-Band Solid State Power Amplifier

Multifunctional Structure



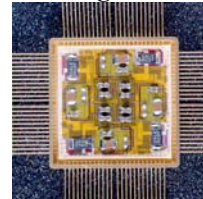
Miniature Integrated Camera Spectrometer



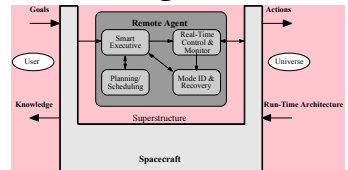
Plasma Experiment for Planetary Exploration



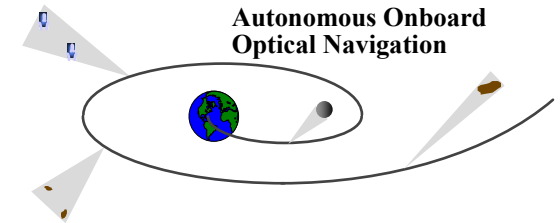
Power Actuation & Switching Module



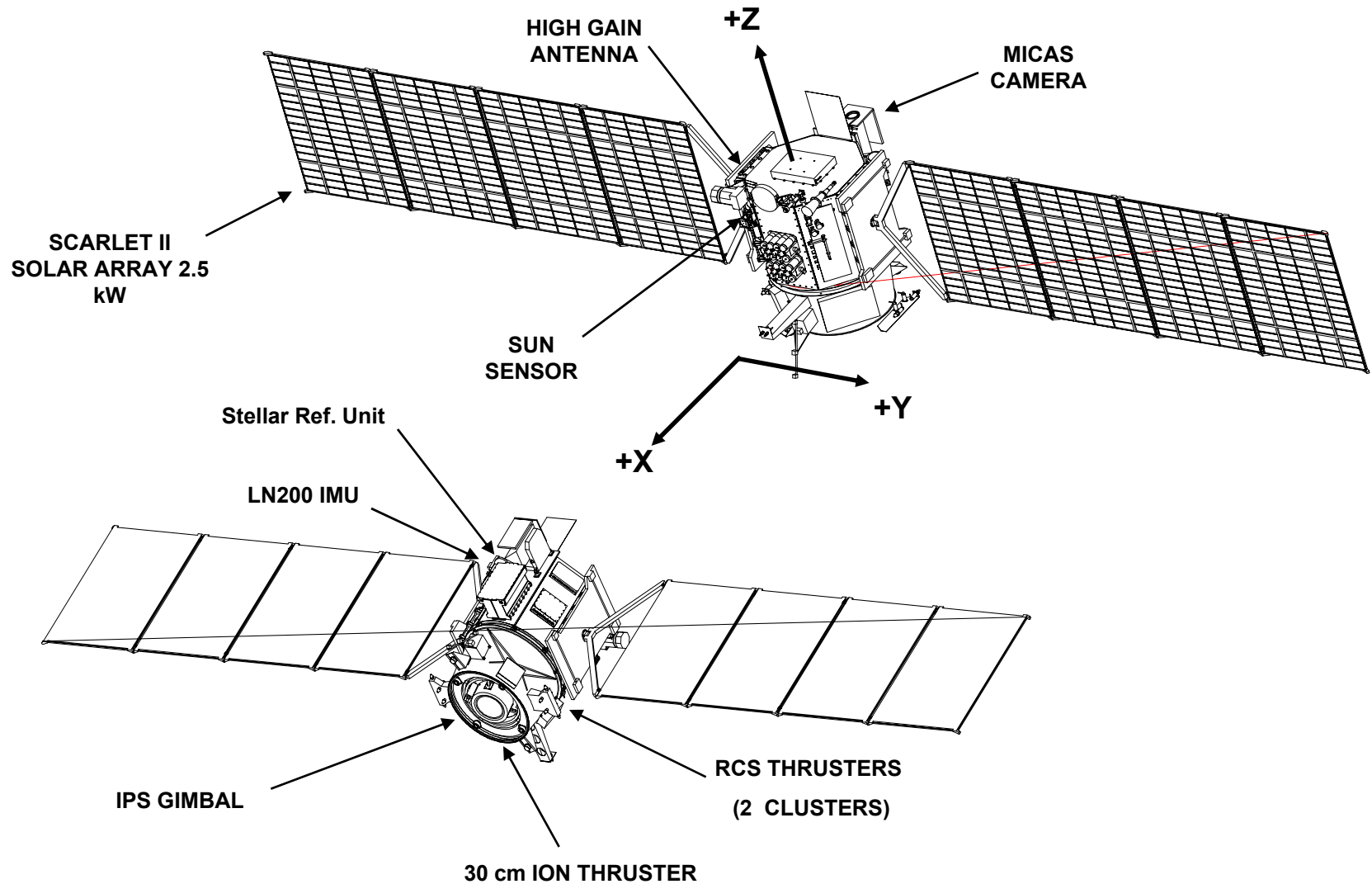
Remote Agent



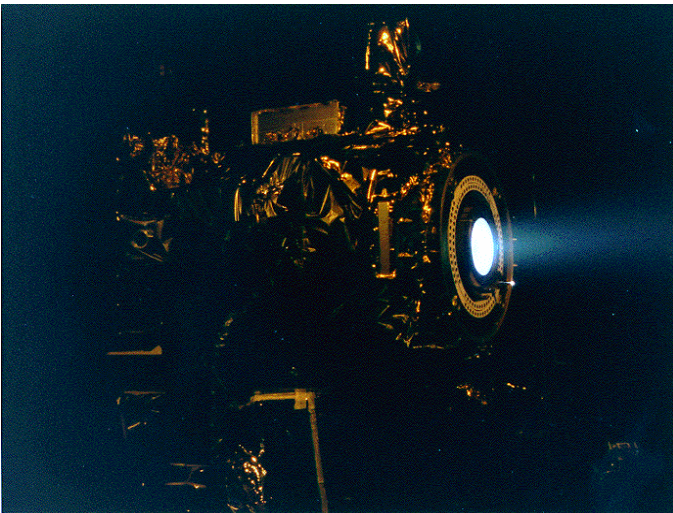
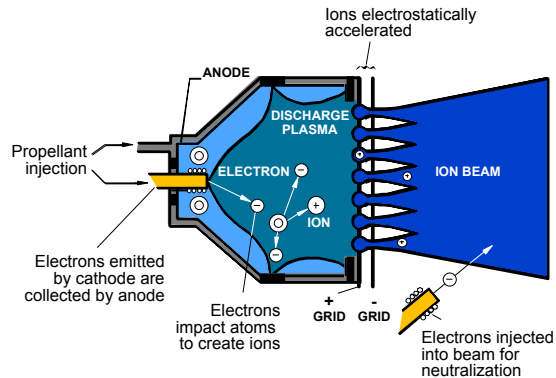
Autonomous Onboard Optical Navigation



DS1 Guidance & Control Configuration



Ion Propulsion System



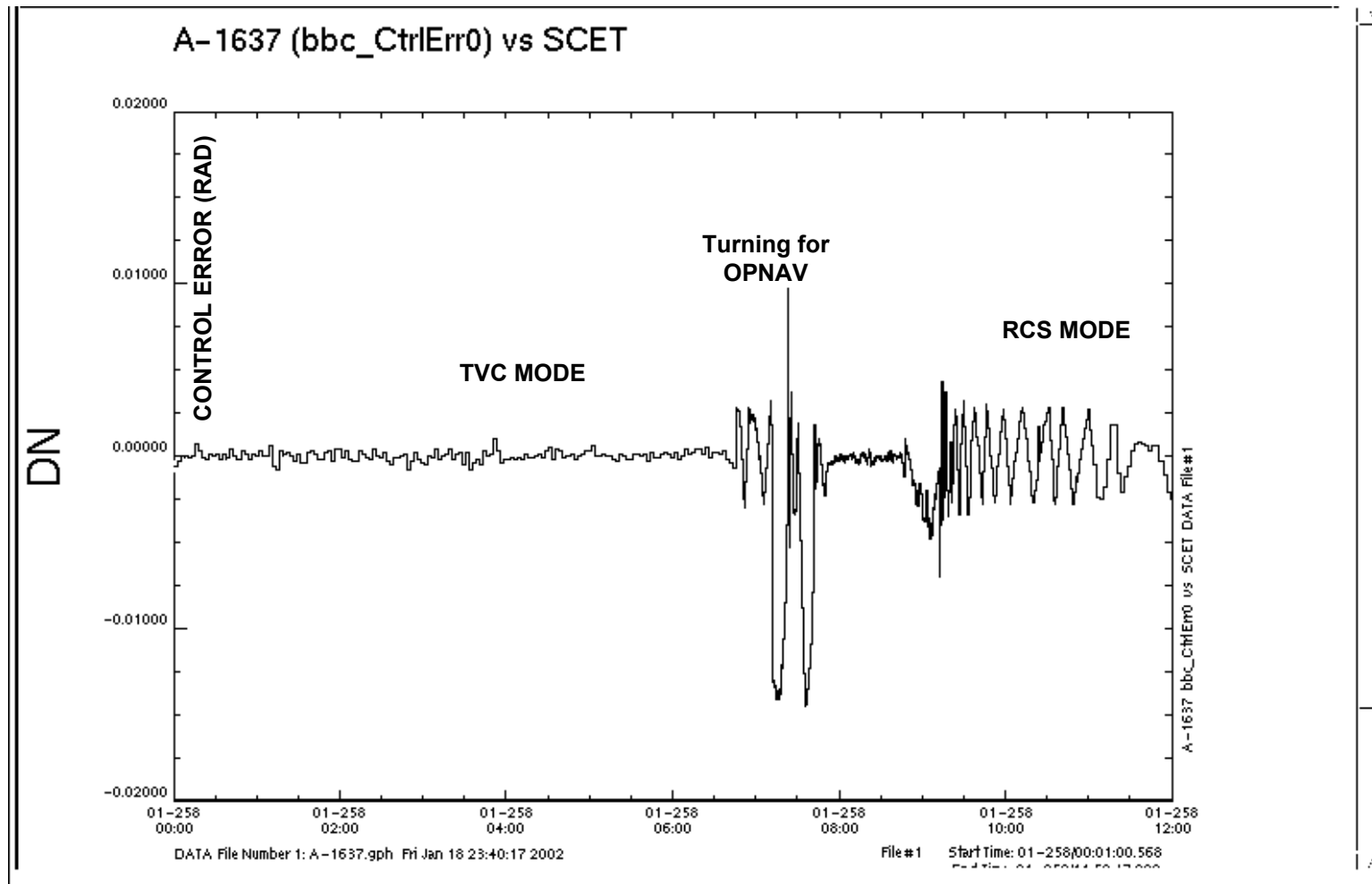
Description

- 30 cm engine provided by NASA NSTAR Program
- Throttleable
 - 20 to 90 mili-Newtons thrust
 - 500 to 2500 W input power
- Typical DS1 operating parameters
 - Input power 1600 W
 - I_{sp} 3000 sec
 - Thrust 60 mili-Newtons
 - Accel voltage 1100 V
 - Exhaust vel ~ 40 km/sec
 - Xe flow rate 2 mg/sec
 - Spacecraft accel 11.5 m/sec per day

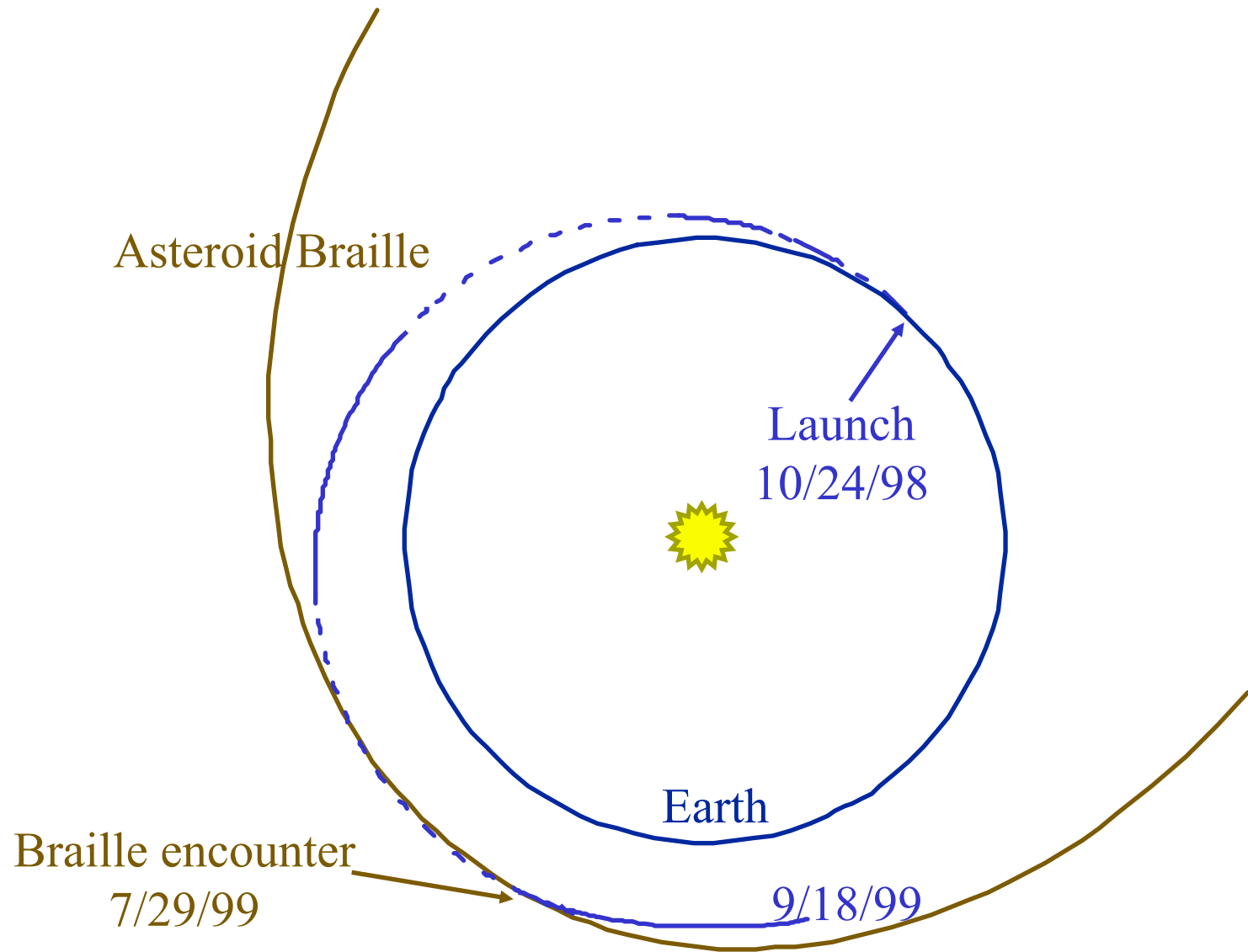
Flight Experience

- 16265 hours (677 days!) trouble-free operation
- 70 kg Xe expended to achieve 4.2 km/sec
- Equiv. mission would require 1200kg bi-prop

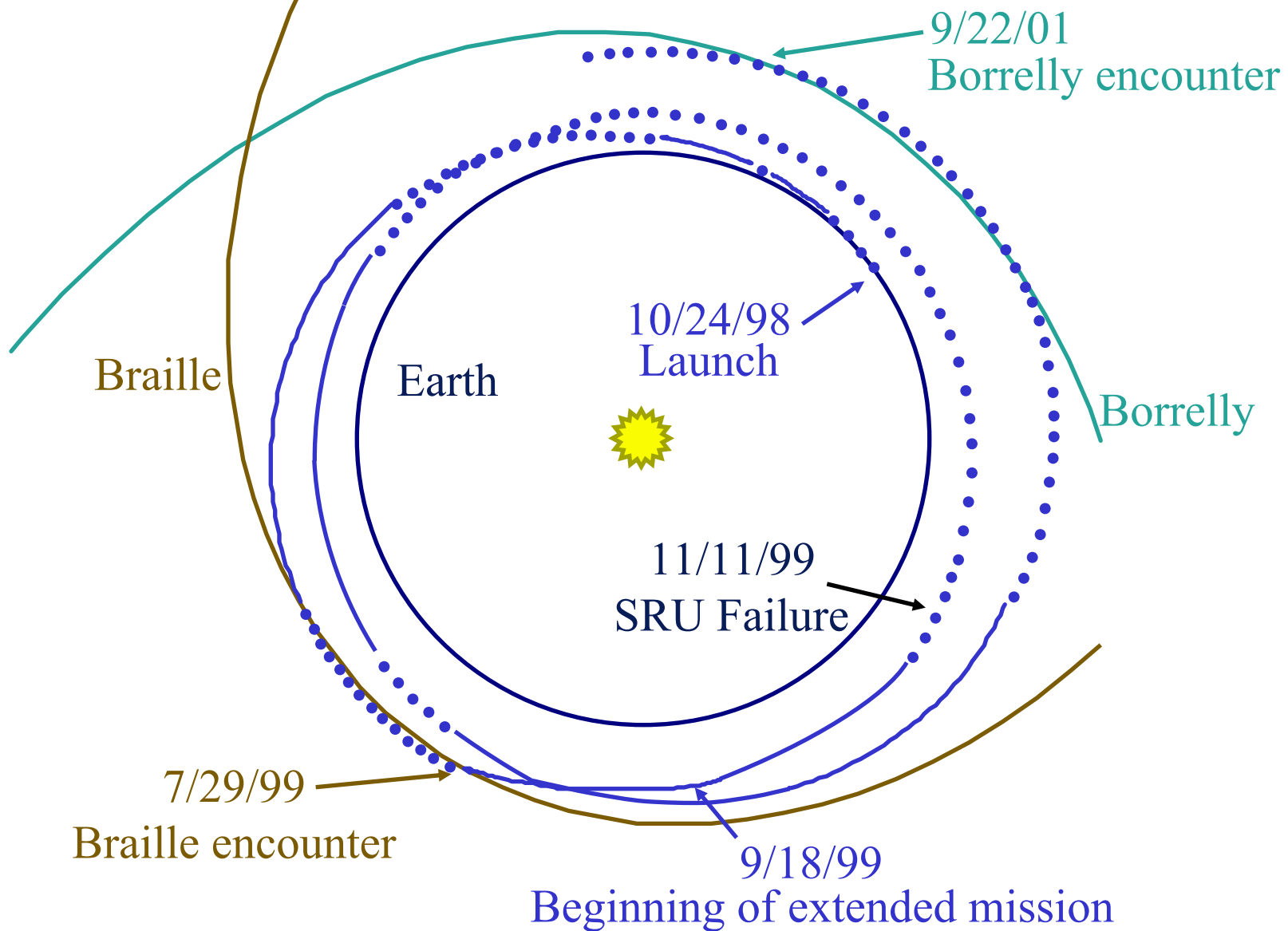
TVC vs. RCS Control Errors



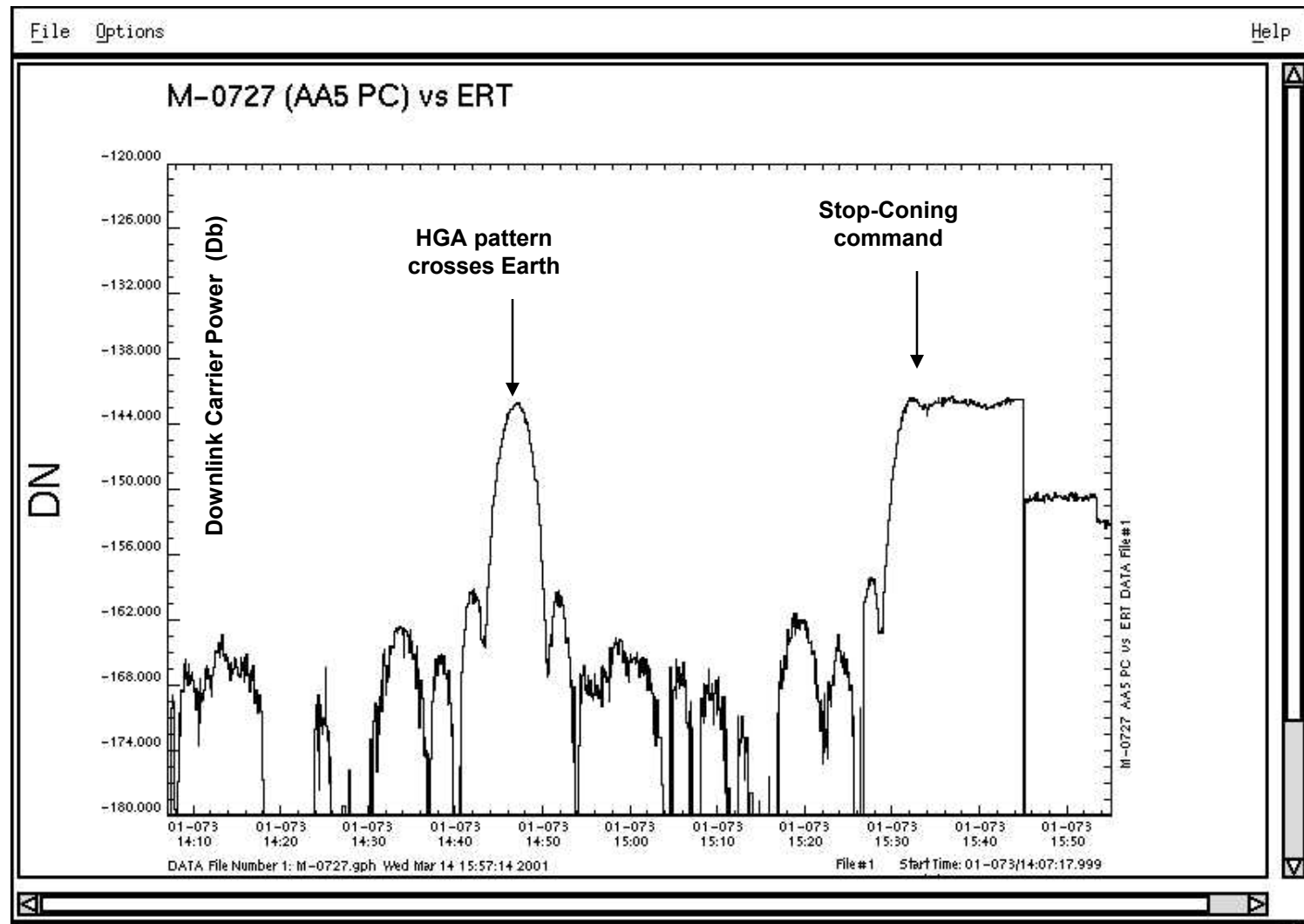
Primary Mission Trajectory



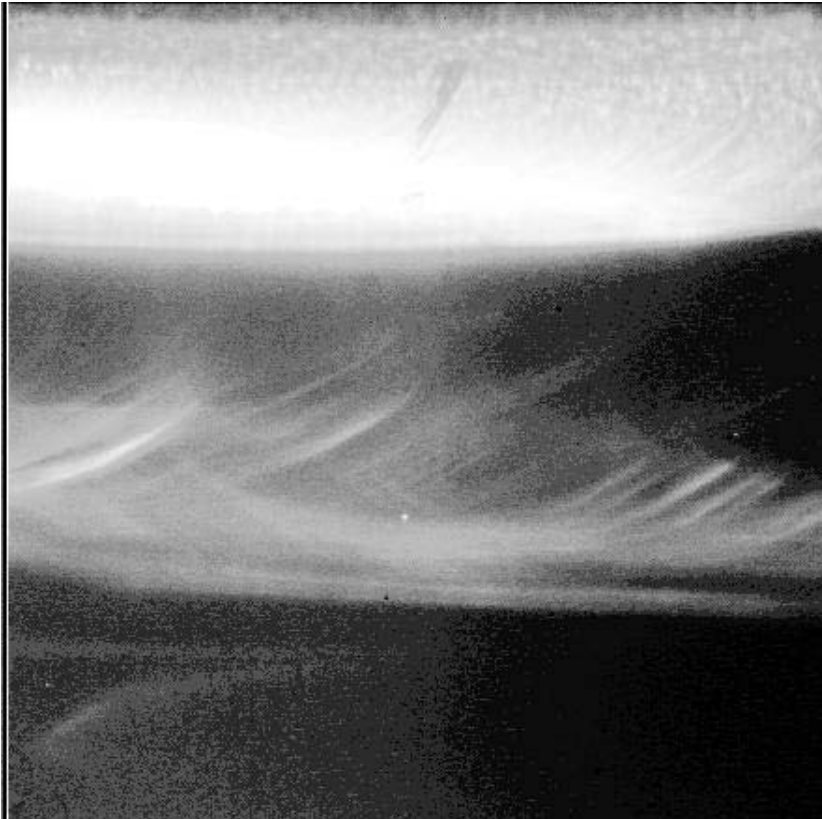
The Road to Borrelly



Downlink Power During Earth Coning



SRU vs. MURKY/MICAS



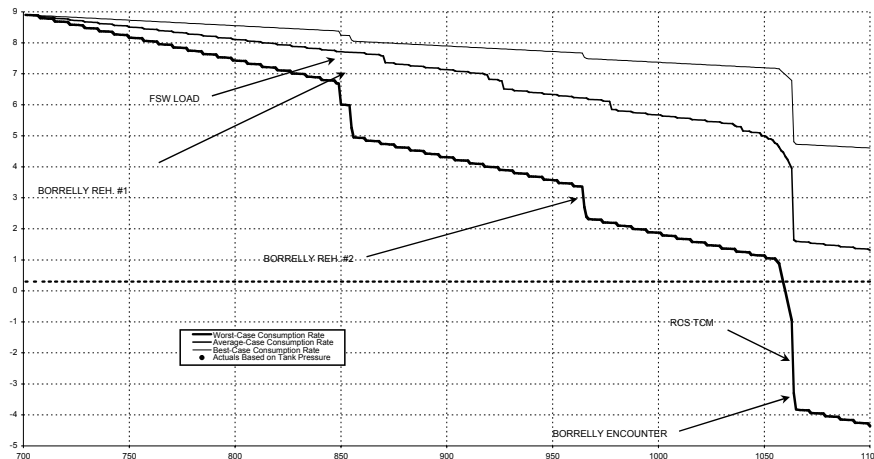
SRU

- 8.8 X 8.8 deg FOV
- Mag 7.5 sensitivity
- 0.25 sec update period
- Provides full attitude quaternion

MURKY using MICAS Camera

- 0.8 X 0.5 deg usable FOV
- Mag 6.5 sensitivity
- 30 sec update period
- Provides image file to MURKY software
- Requires sun sensor data to compute full 3-axis attitude

ACS Encounter Challenges



Hydrazine Budget assuming “impulse power”

Radius (mm)	Count	Momentum (Ns)	Energy (J)
0.1	10	0.00007	0.576
0.3	8	0.0019	15.6
0.5	2	0.0086	72
1.0	0.4	0.069	576 !

Debris Predict @ 2000 Km, 16.6 Km/sec

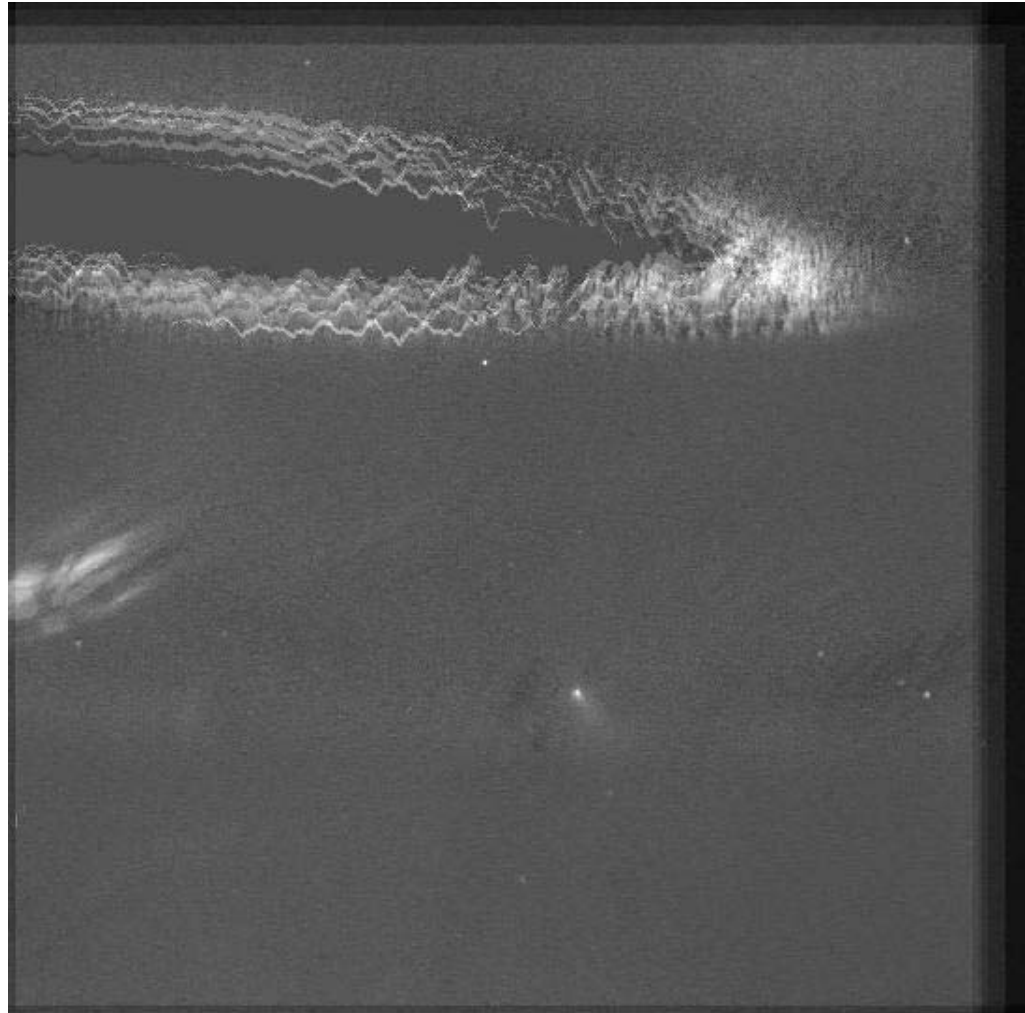
Gyro Performance

- Scale factor errors undetectable
- Developed gyro stochastic model for testing
- NAV included attitude states in flyby estimator
- “Rolled the dice” on ~monthly IMU reset

RCS Control Gains

- Tight timing of encounter seq called for high confidence in gains, turn settle times
- Pulse-mode thrust estimated directly from deadband motion, testbed updated to match
- Produced good agreement between flight encounter rehearsal and testbed runs.

SOB9 Co-Add Image of Borrelly





Borrelly Jet Details



